HIGH GRADIENT INSULATOR TECHNOLOGY FOR THE DIELECTRIC WALL ACCELERATOR*

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Insulators composed of finely spaced alternating layers of dielectric and metal are thought to minimize secondary emission avalanche (SEA) growth. Most data to date was taken with small samples (order 10 cm^2 area) in the absence of an ion or electron beam. We have begun long pulse (>1 μs) high voltage testing of small hard seal samples. Further, we have performed short pulse (20 ns) high voltage testing of moderate scale bonded samples (order 100 cm^2 area) in the presence of a 1 kA electron beam. Results thus far indicate a 1.0 to 4.0 increase in the breakdown electric field stress is possible with this technology.

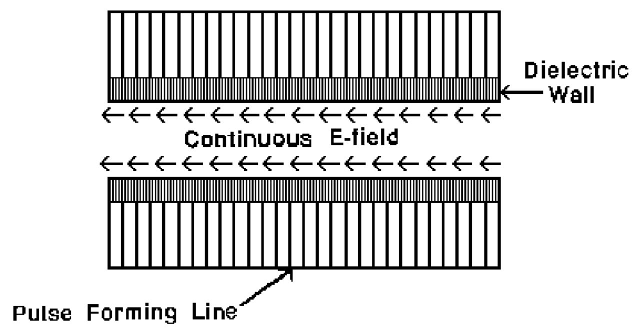

Figure 1. Dielectric Wall Accelerator (DWA).

I. INTRODUCTION

The dielectric wall accelerator (DWA) is a new accelerator concept particularly suited for short pulse (<50 ns) and high currents (>1 kA). As we previously presented, the pulsed acceleration field is developed by a series of asymmetric Blumleins (i.e., pulse forming lines) incorporated into the insulator structure (Fig. 1) [1,2].

The maximum gradient of this accelerator is defined by the dielectric strength of the wall dielectrics and the maximum surface flashover electric field capability of the interior vacuum interface in the acceleration region. Solid insulator materials can typically meet the 20-30 MV/m requirement; the interface at the vacuum wall typically cannot.

High electric fields are possible with properly angled insulators. These insulators, however, are generally unipolar and are not optimum in the simplest configuration of the DWA (i.e., Fig. 1, where the electric field in the dielectric is always applied to the insulators). Thus we select a straight wall insulator as optimum.

Typical data for conventional straight wall vacuum insulators is shown in Figure 2. It is clear from this data, that to achieve the necessary gradients, alternate technologies should be investigated.

Improvements to existing technology can be made based on an understanding of the failure process. The most simplified vacuum surface breakdown model suggests that electrons originating from the cathode-insulator junction are responsible for initiating the failure [3]. When these electrons are intercepted by the insulator surface, additional electrons,

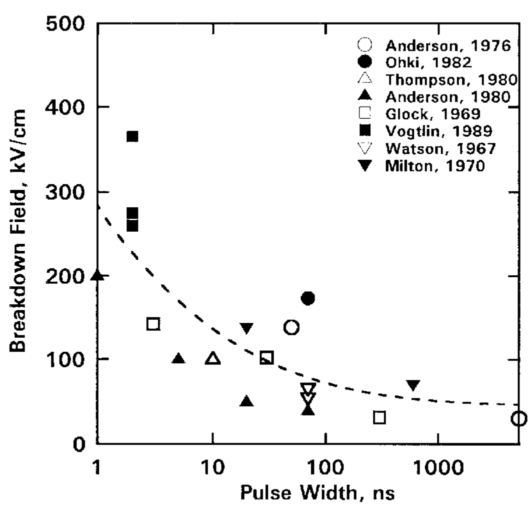

Figure 2. Breakdown thresholds for 0° vacuum insulators.

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based on the secondary emission coefficient, are liberated. This effect leaves a net positive charge on the insulator surface, attracting more electrons and leading to escalation of the effect or the so-called secondary emission avalanche breakdown (SEA).

It has been shown that full evolution of the streamer discharge occurs within a fraction of a millimeter [4]. Placing slightly protruding metallic structures spaced at an equivalent interval is believed to interrupt the SEA process and allow the insulator to achieve higher gradients before failure [5,6]. This is the high gradient insulator concept being developed. When the DWA is combined with this high gradient vacuum insulator technology, short-pulse-high-gradients of greater than 20-30 MV/m may be possible.

II. APPARATUS

Several small sample (approximately 2.5 cm diameter by 0.5 cm thick) insulators were fabricated. The first was fabricated from interleaved layers of 0.064 mm stainless steel and 0.127 mm polycarbonate film. Two other small hard seal samples were fabricated from alumina and fused silica. The alumina sample was fabricated with 0.28 mm thick material and the fused silica sample was fabricated with 0.25 mm thick material. The interleaved metallic layers were formed by depositing gold on each planar insulator surface by a sputtering technique and then bonding the stacked layers by heating while applying pressure. Concentricity was ensured by performing a finish grinding operation.

Small sample testing was performed in a turbo-molecular pumped, stainless-steel chamber at approximately 10^{-6} T. High voltage was developed with a 10 J "mini-Marx". The Marx developed a pulsed voltage of approximately 1.3 μs, FWHM (3 μs, base-to-base) and up to 250 kV amplitude across the sample. Failure of the insulator was determined by a prompt increase in Marx current and a corresponding prompt collapse in the voltage across the sample.

Dimensions of the larger high gradient insulator were 14.5 cm I.D. by 22.1 cm O.D. by 2 cm length. The structure consisted of multiple kapton sheets layered and thermally bonded to form a single 45^{o} stepped conic section on the interior of the stack between each stainless steel grading ring. Spacing between each grading ring was 1-2 mm. Supporting stainless steel flanges, bonded to each end of the insulator structure, provided mechanical attachment to the remaining structure.

Testing the larger, high gradient insulator structure in the presence of an electron beam was performed with a 1 MV, 20 ns, oil insulated Blumlein pulse generator. A 2 cm diameter velvet emitter, bonded to an aluminum cathode support plate, was used to generate the electron beam. Unwanted emission in the area immediately next to the emitter was suppressed by applying a hard anodized coating.

Transport between the emitter and graphite collector was done by placing highly transparent (96%) tungsten meshes in the beamline. These meshes locally short out the radial component of the electric field. Convergence then results from the self-magnetic field of the beam. Optimized placement of the meshes was determined using GYMNOS [7] and full transport required three meshes; one at the anode plane and two spaced at 12 cm and 21 cm from the cathode.

II. EXPERIMENTAL RESULTS AND DISCUSSION

Small sample high voltage testing results are tabulated in Table I. To obtain a particular data set, the insulators were subjected to several low voltage conditioning pulses. The voltage was then increased a small amount incrementally until breakdown occurred. Voltage was then reduced for several shots and then incrementally increased again until a consistent value resulted.

From this method, we measured an ultimate flashover strength for the small samples of approximately 125 kV/cm for the alumina substrate, 175 kV/cm for the fused silica substrate and 200 kV/cm for the polycarbonate substrate for a pulse width of 1.3 μs, FWHM. The trend in conventional technology (Fig. 2) for 0^{o} insulators indicates a breakdown threshold of approximately 50 kV/cm. Thus, there was a net increase in the performance with these insulators over conventional technology of 2.5, 3.5, and 4.0, respectively.

Table I. Small sample tests results

SUBSTRATE	BREAKDOWN FIELD
Polycarbonate	200 kV/cm
Fused Silica	175$^{a)}$
Alumina	125

a) Type III anodized coating on electrodes

A similar scenario was used to determine the flashover strength of the larger high gradient insulator with and without an electron emitter installed. A total of 125 pulses at different voltages without the emitter installed were taken; 35 additional shots with the 2 cm diameter velvet emitter in place were also taken. These two tests were performed to determine the effects of an emitter and electron beam in the vicinity of the insulator.

A slightly different manifestation of failure was observed in these tests (Fig. 3). For fields above 190 kV/cm, we observed an increased collector current up to about 210 kV/cm when we observed late-time, fast transient currents and a decreased voltage pulse. The normal signature of an insulator failure, i.e., prompt and complete collapse of the voltage, was not observed until about 250 kV/cm. These observations lead us to believe that the primary failure mechanism was resulting from strong explosive emission occurring in the vacuum gap.

Further manifestations of this effect is shown in Figure 4. Below about 210 kV/cm, we observed currents consistent with the GYMNOS predictions. Above an electric field of 210 kV/cm, we began to observe a strong trend away from this predicted current; 1.6 kA compared with the predicted 1.1 kA at 250 kV/cm. We observed this ultimate threshold

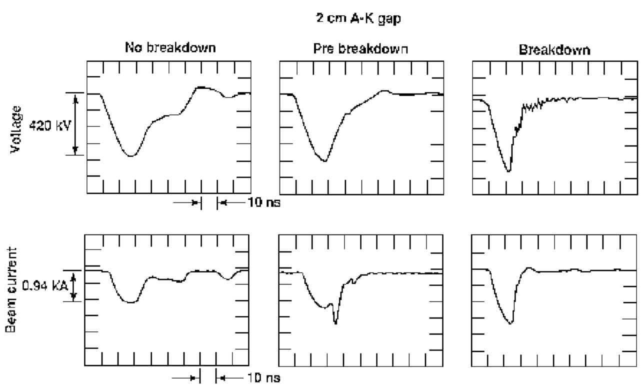

Figure 3. Typical pre-breakdown and closure pulses

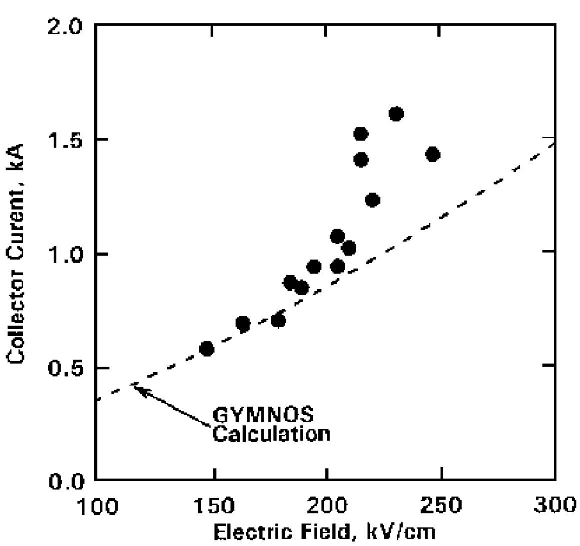

Figure 4. Comparison of predicted and measured currents.

to be consistent with breakdown data taken in the absence of an electron beam.

Further physical evidence of this failure mode was observed upon opening the structure; we observed explosive emission sites, i.e. pitting on the stainless steel cathode structure supporting the insulator.

Further testing of this structure is planned. In these upcoming experiments, we intend to test the effects of explosive emission suppression coatings on the entire cathode electrode surface and the metallic gradient rings within the high gradient insulator.

IV. SUMMARY

We began testing a new high gradient insulator technology. The insulator consists of finely spaced metal electrodes interleaved with the insulator substrate. The spacing of these metal electrodes is on the order of a streamer formation distance. For small samples, we observed significant improvement over conventional 0^{o} insulators subjected to long pulse fields. For moderate size insulators in the presence of an electron beam, we observed slightly reduced improvement but begin to observe the effects of explosive emission from the cathode surface.

V. REFERENCES

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